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Tracing Cosmic Evolution with an *XMM* Serendipitous Cluster Survey

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Abstract.
   This paper describes updated predictions, as a function of the underlying cosmological model, for a serendipitous galaxy cluster survey that we plan to conduct with the *XMM-Newton* X-ray Satellite. We have included the effects of the higher than anticipated internal background count rates and have expanded our predictions to include clusters detected at $> 3\sigma$. Even with the enhanced background levels, we expect the XCS to detect sufficient clusters at $z > 1$ to differentiate between open and flat cosmological models. We have compared the XCS cluster redshift distribution to those expected from the *XMM* Slew Survey and the *ROSAT* Massive Cluster Survey (MACS) and find them to be complementary. We conclude that the future existence of the XCS should not deter the launch of a dedicated X-ray survey satellite.

$T > 4$ keV	$\Omega_0 = 0.3, \Omega_\Lambda = 0.7$			$\Omega_0 = 1.0, \Omega_\Lambda = 0.0$			$\Omega_0 = 0.3, \Omega_\Lambda = 0.0$		
	$> 8\sigma$	$> 8\sigma$	$> 3\sigma$	$> 8\sigma$	$> 8\sigma$	$> 3\sigma$	$> 8\sigma$	$> 8\sigma$	$> 3\sigma$
	i	ii	iii	i	ii	iii	i	ii	iii
$z > 0$	750	720	890	80	80	80	1100	1010	1530
$z > 0.3$	700	660	830	50	50	50	1060*	970	1490
$z > 1$	170	150	300	1	1	2	480	390	900

Table 1.   The expected number of $T > 4$ keV clusters detected by the XCS as a function of cosmology. Column i, the original XCS predictions for $> 8\sigma$ detections from R01. Columns ii and iii, updated XCS predictions based on the measured in flight internal background count rate. All the results assume a final survey area of 800 sq. degrees. *There was a typo in the the printed version of R01, this is the correct value.

1.   Introduction

In an earlier paper (Romer et al. 2001, R01 hereafter) we described the expected catalog properties and scientific applications of an *XMM-Newton* Cluster Survey (XCS) based on serendipitous detections in pointed observations. We revisit these predictions below, in light of improved knowledge of the in flight performance of *XMM*. We also compare the XCS to other on-going X-ray surveys.

2.   The Effect of an Enhanced Internal Background Count Rate on the XCS

Recently it has come to light that the quiescent internal background count rates in the EPIC detectors are roughly ten times higher than was anticipated prior to the *XMM-Newton* launch (see Lumb 2001). We have, therefore, recomputed the expected properties of the XCS cluster catalog using a total (external plus internal) background level that is roughly double that used in R01. In Table 1, we compare the new predictions (column ii) with those published in Table 4 of R01 (column i). For example, for an open model ($\Omega_0 = 0.3$, $\Omega_\Lambda = 0$), we now predict that the XCS will detect 390 $T > 4$ keV, $z > 1$ clusters at $> 8\sigma$, compared to 480 in R01. Changes at that level should not severely limit the ability of XCS to differentiate between open and flat cosmological models.

We have also included in Table 1 predictions for the number of XCS clusters that would be detected at $> 3\sigma$. We did not include low signal to noise detections in R01 because they will be hard to identify using an extent criterion alone. However, when combined with Planck and/or SDSS data, it may be possible to identify these objects in a timely and quantifiable manner, so we include them here for completeness.

The redshift distribution of the $> 3\sigma$ and $> 8\sigma$ XCS detections can be seen in Figure 1.
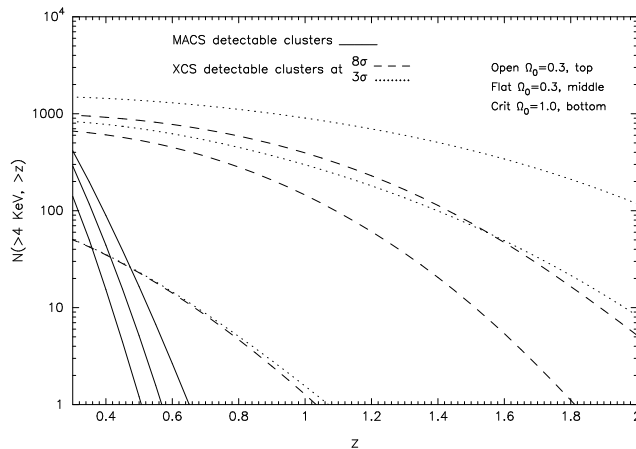
Figure 1. Predicted redshift distribution ($z > 0.3$) of MACS clusters (solid lines) and of the XCS Survey (dashed and dotted lines).

3. Comparisons with the MACS and *XMM* Slew Surveys

The Massive Cluster Survey (MACS, Ebeling, Edge & Henry 2001) has been very successful at identifying high redshift, high luminosity, clusters detected in 22,735 square degrees of the ROSAT All Sky Survey. The wide areal coverage of the MACS (nearly 30 times that of the XCS!) results in sensitivity to a very interesting class of clusters, those at medium redshift and high luminosity ($L_x > 5 \times 10^{44}$ erg cm^{-2} s^{-1}; 0.1-2.0 keV). MACS clusters are already being used for a variety science programs including studies of cluster evolution and the Sunyaev-Zel'dovich Effect.

Using the R01 methodology and based on the MACS selection function presented in Figure 5 of Ebeling et al. (2001) we have been able to predict the number of clusters that would be detected by MACS as a function of cosmology. We present those results in Figure 1 and Table 1. Overall, we can expect MACS to detect between 100 and 500 clusters at $z > 0.3$, depending on cosmology.

An *XMM* Slew Survey has been proposed (*e.g.* Lumb & Jones 2000). An *XMM* Slew survey would have two important advantages over the XCS; it would be drawn from random parts of the sky (rather than from regions that surround known X-ray targets) and it would cover significantly more area. Lumb & Jones (2000) estimated an annual survey rate of 4000 square degrees to a flux limit of 2×10^{-13} erg cm^{-2} s^{-1} (0.5-2.0 keV). This compares to an estimated annual survey rate for the XCS of $\simeq 80$ square degrees (the XCS catalog will not have a single flux limit, but a typical value will be $\simeq 1.5 \times 10^{-14}$ erg cm^{-2} s^{-1} in the 0.5-2.0 keV band, see R01).

We have attempted to predict the properties of a Slew Survey cluster catalog using the R01 methodology. At the time of writing, the Slew Survey had only just begun and the actual sensitivity level was unknown (Lumb, private communication). We, therefore, present results for two different (0.5-2.0 keV) flux limits; 2×10^{-13} erg cm^{-2} s^{-1} and 3×10^{-12} erg cm^{-2} s^{-1}, see Figure 2. We have assumed that 4000 square degrees would be covered in one year by the
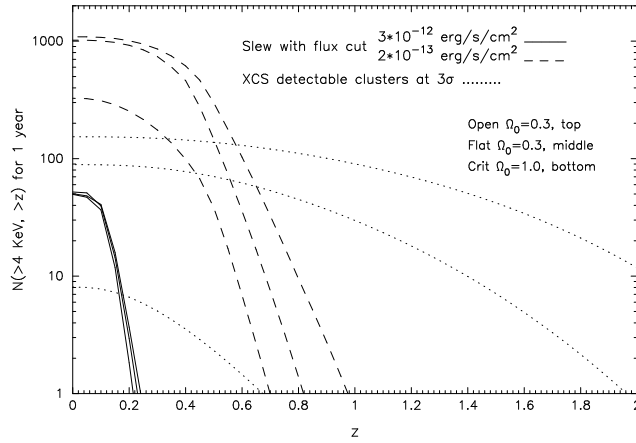
Figure 2.   Predicted redshift distribution of the clusters detected during the first year of an *XMM* Slew Survey (solid and dashed lines) and of the XCS Survey (dotted lines).

Slew Survey. For comparison we have shown the expected numbers of clusters that would be detected at $> 3\sigma$ in one year of the XCS (or 80 square degrees).

A Slew Survey with 2×10^{-13} erg cm^{-2} s^{-1} sensitivity would produce a very impressive cluster catalog at low and medium redshifts. Such a catalog would have a variety of applications including constraints on σ_8 and Ω_0 and studies of cluster evolution and Planck foregrounds.

In summary, the MACS and the *XMM* Slew Surveys have much better low redshift sensitivity than XCS by virtue of their large areal coverage. However, neither will be able to differentiate between open and flat low Ω_0 models, because they lack sensitivity to high redshift clusters. These surveys should be seen as complementary too, not in competition with, the XCS.

The XCS faces many challenges, including the complexity of its selection function and our lack of understanding of cluster evolution. The future existence of the XCS should not deter the launch of a dedicated X-ray survey satellite.

References

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